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X-ray Scattering Investigation of Epitaxial Bi Thin Films Grown on Ge(001)

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Beamline(s):X16A

Introduction: Bismuth is a semimetal that posses many interesting electronic properties. In thin film form, Bismuth has displayed quantum size effects, nonlinear optical properties and superconductivity. Additionally, the theoretical prediction that a semimetal to semiconductor transition occurs at a critical thickness has been confirmed. Recently it has been shown that Single Crystal Bi films have resistance values as low as 89 μohm at 5K[1]. This is approximately an order of magnitude improvement over previous studies where polycrystalline Bi films were made by evaporation or sputtering. We used MBE to evaporate thin Bi films (less than 600 Å) onto Ge(001) and measured both specular and off-specular CTRs (Crystal Truncation Rods) in ultra-high vacuum.

Methods and Materials: The Bi films were deposited and measured *in-situ* at the NSLS X16A beamline. The base pressure of the vacuum system was $2x10^{-10}$ Torr and the Ge(001) substrate was sputter cleaned a with 1KeV Ar+ ions and annealed to 690^{o} until a sharp two-domain 2x1 reconstruction was obtained. Bi was evaporated from an electron beam source while the Ge(001)substrate was at room temperature. The substrate was then annealed to 200^{o}C for five minutes before proceeding with the x-ray measurements. The Si(111) double crystal monochromater was tuned to 10.5 KeV for the experiment and data was taken on five different samples ranging from 49 Å to 570 Å in thickness as determined by specular reflectivity.

Results: At room temperature, bulk Bismuth has a rhombohedral crystal structure with an $\bar{a}$ and $\bar{b}$ lattice constant of 4.55 Å and $\bar{c}$ lattice constant of 11.86 Å. Since atomically clean Ge (001) has an in-plane lattice constant of 4.0 Å it is reasonable to assume that Bi could grow epitaxially on Ge(001) with the Bi trigonal axis orientated normal to the Ge(001) surface. Figure 1 is an 00L specular scan (Ge units for L) for a 142 Å thick film. The peaks at L= 1.38 and L= 2.76 are the Bi (003) and Bi (006) Bragg reflections, thus verifying that the film grows with the trigonal axis orientated perpendicular to the substrate. Many studies have noted that electron mobilites in Bi thin films are highly anisotropic. This is due to the fact that the in-plane structure of the Bi films are often polycrystalline, or twinned and thus the scattering of electrons is increased. We scanned our samples in-plane (HK scan) across Bi peaks in order to measure the in-plane domain size of the Bi film. From STM it has been proposed that after 1 ML Bi grows as islands on Ge(001)[2]. We have observed that the in-plane domain size of these films increased from 47 Å to 120 Å as the film thickness increased from 49 Å to 570 Å. This suggests that if indeed Bi grows as islands on Ge(001),the islands tend to coalesce as the film thickness increases.

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References: [1]F.Y. Yang , Kai Liu et al. Science **284** *1335*. 1999. [2]H.K. Louwsma, H.J.W. Zandvliet et al. Surface Science. **381** *594* 1997.

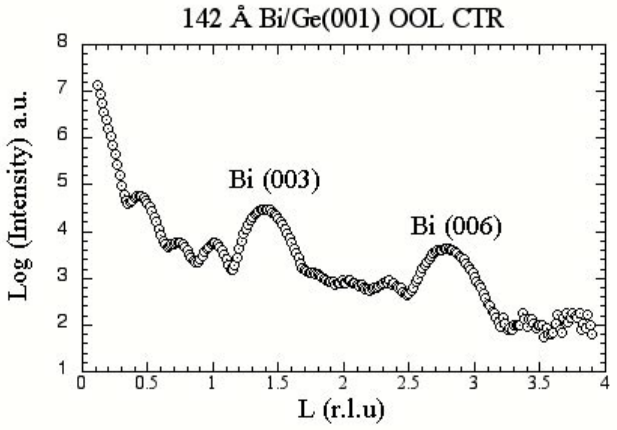

Figure 1 Specular Reflectivity of 142 Å Bi/Ge(001)